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OHIO BASIN REGION

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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LAND SPREADING, A CONSERVING AND NON-POLLUTING METHOD OF DISPOSING OF OILY WASTES

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INTRODUCTION

Disposal of concentrated wastes is a problem of increasing concern for public officials, industrialists, conservationists and the general public. Some of the most complex wastes are those associated with petroleum. The use of petroleum products has increased rapidly in the industrialized areas of the world in the last 30 years. Though this increase has resulted in many new products and has contributed greatly to the economics of the areas involved, it has added to the problem of waste treatment and disposal. Oil and several of the chemical wastes from petroleum refining and processing are serious pollutants of surface water and land when discharged without adequate treatment and proper disposal. Extracting, transporting, refining, and selling of the petroleum products are operations with potential for polluting water. Dredging oily sludge from channels and harbors may pollute lakes and streams when the sludge is dumped back into open water. Several American refineries are reported to dispose of oily sludge on the land. This paper discusses land spreading operations for oily waste disposal by three refineries.

Use of land as a receptacle for organic wastes is an ancient practice that holds much promise for treatment and disposal of organic and some inorganic wastes in the future. Transporting digested sludge for almost 100 miles from Cleveland to strip mined areas for disposal was suggested by Wirts (1956). Economical conveyance by pipeline makes land spreading feasible for some municipalities to which land was previously unavailable. Dalton et al. (1967) calculated that land spreading of liquid digested sludge on low-productivity sandy soils after piping more than 50 miles (80.5 kilometers) would be less than half as expensive as other methods of dewatering and disposing of Chicago sludge. Templeton (1966) found land spreading at East Kilbride, Scotland, to be competitive with sea disposal or other methods and to be virtually trouble free and independent of weather conditions. Many other plants in this country and abroad continue to use land spreading even though they have installed more complicated sludge dewatering devices.

Soils have been shown to provide a high degree of physical, chemical, and biological treatment for organic wastes when the system is properly designed. Despite their demonstrated efficiency in assimilating wastes, land spreading has never been used as extensively as it could be. Although used by many petroleum refineries, oily waste disposal by land spreading has not been generally appreciated and exploited by sanitation and pollution control officials. Several reasons are apparent for the practice having failed to be used more universally. Disposal of putrescible wastes causing unfavorable public reaction; fear of pollution of surface and ground water; using soils poorly suited to sludge assimilation; and lack of information concerning successful full-scale operations are among the reasons.

UTILIZATION OF WASTES BY SOIL MICROBES

The soil is an excellent medium for growing microbes, thus it is capable of assimilating and decomposing organic matter. Soil as described by Smith (1960) is the collection of natural bodies at the earth's surface containing living matter and supporting or capable of supporting plants. Many kinds of soils have developed through interactions of climate, living organisms, parent materials, and relief. So, while living organisms have been influential in determining the kind of soil at a given location, the resulting soil properties influence greatly the kinds and numbers of microbes living within. The soil is a complex dynamic system with continuous chemical, physical, and biological activity. Any sudden change in the environment, such as addition of oil, causes a change in soil properties, but when the cause of change is removed the soil again moves toward equilibrium with the environment.

Although soils vary from place to place in the quantity and kinds of microorganisms, most soils contain many millions or billions of microbes per gram (Waksman, 1931), the greatest number of organisms usually living near the surface. A sufficient quantity of mineral nutrients and organic matter, near-neutral pH, warm soil, and abundance of air are conditions that are favorable for reproduction and growth of microbes. Fungi are more amenable to acid soils than bacteria (Waksman, 1931). Bacteria outnumber fungi in most soils by a large margin and they reproduce much faster so it is likely that bacteria are responsible for much of the decomposition of hydrocarbons in soil.

Crude oil and the wastes that result from its processing are complex mixtures, so it is probable that few if any microbes will attack all fractions. A mixed population such as that in soils is more efficient than a single class of microbes. Petroleum hydrocarbons vary in susceptibility to decomposition. High molecular weight, viscosity, and crystallinity are properties that inhibit biological oxidation and decomposition. Straight chain medium molecular weight hydrocarbons such as kerosene and light motor oils oxidize readily, while aromatic types are more resistant.

Many studies of microbes capable of utilizing petroleum hydrocarbons have produced a list of more than 100 species and 30 genera of bacteria, actinomycetes, and fungi that attack one or more fractions of crude oil. Ellis and Adams (1961), citing Haas (1942), reported that 66% of the hydrocarbon oxidizers found in ordinary soils were *Pseudomonas* species. *Pseudomonas* can grow under a wide range of conditions and with very little food. They are prevalent in populations where petroleum hydrocarbons are available and in activated sludge.

There is much evidence, other than that from research studies, to attest to the capacity of soil microbes to assimilate hydrocarbons. Peculiar accumulations of organic matter near the soil surface have been shown to be associated with gas seeps and petroleum deposits. The organic deposits, called "paraffin dirt" because of their waxy appearance, consist of cells of hydrocarbon utilizing microbes, and colloidal organic material produced by them, and are used as a tool in prospecting for petroleum (Davis, 1967).

Decomposition of the asphalt coating used to protect some underground pipes from corrosion is credited to microbes which have been found to be present in unusually large numbers around such pipes. Asphalt used in combination with wheat straw by conservationists and engineers to mulch ditch banks is decomposed at about the same rate as the straw.

Seepages of oil and natural gas have doubtless existed in nature for centuries without producing lakes of oil or high hydrocarbon accumulations in the atmosphere. Microbial

assimilation in the soil is postulated (Ellis and Adams, 1961) to be the cause of this phenomenon.

The three land spreading operations described in this paper illustrate different techniques of disposing of oily sludge by land spreading.

LAND DISPOSAL PRACTICES

The Humble Oil Company, Baytown, near Houston, Texas has disposed of oily sludge from gravity oil-water separators by spreading on land for about 16 years. The sludge is pumped from the bottom of API oil-water separators into one of two storage pits where it remains for one to two years. When a pit is full it is dewatered by decanting and the sludge removed by a clamshell to dump trucks and hauled to adjacent grassland where it is dumped and spread with a bulldozer. After partial drying the sludge is incorporated into the soil by disking with a large heavy-duty disk and a crawler type tractor. A single disking is used to mix soil and sludge and stimulate biological decomposition.

The land consists of clay soils. Tests of soil samples taken prior to the beginning of sludge spreading indicated a pH of 4.4 to 4.8 in the topsoil. The content of available nitrogen was medium, and available phosphorus was low. Two tons of agricultural ground limestone, 50 pounds of nitrogen per acre (56 Kg/Ha), and 60 pounds of phosphorus per acre (67 Kg/Ha) were applied once, but the application was not repeated. No further soil testing was done. The purpose of fertilizing and liming was to produce a favorable medium for microbial activity and not to fertilize the grass.

An average API oil-water separator sludge consisted of an emulsion with about 20% hydrocarbon, 25% solids, and 55% water. The solids come from unclarified river water, storm water runoff, and precipitates in the system and weight of the emulsion so that it is heavier than water. The sludge is spread to a thickness of about four to five inches (10 to 12.5 cm). Thus about one inch (2.5 cm) of hydrocarbons, equivalent to about 100 tons per acre (110 metric tons/Ha) is applied.

By the time that the sludge is dry enough to work into the soil, the grass has started to grow. It is growing noticeably in three to four months and has usually established a normal grass cover within a year.

Shell Oil Company's refinery at Houston, Texas has successfully used an intensive land spreading system for disposing of nearly all of its petroleum sludges and stable emulsions from tank bottoms, oil-water separators, sewer boxes, and ship ballast water since 1961. The tract of land used consists of approximately seven acres (2.83 hectares). It is divided into four nearly equal sections by built-up roads. The characteristics of the soils in the disposal area have been altered by man's activities, which include the dredging of the Houston ship channel and construction of the disposal area, but H.V. Geib et al. (1928) described the natural soils in the area as clayey or fine textured, naturally poorly drained, and neutral or calcareous in reaction.

The climate at Houston, Texas is characterized by hot summers and mild winters. The average July temperature is 83°F (28°C) and the average for January is 54°F (12°C). The average date of the last killing frost in the winter is February 10 and the first one in the fall is December 8. The average growing season is 301 days. The maximum temperature of record was 108°F (42°C) and the minimum was 5°F (−15°C). Forty-five inches (112 cm) of precipitation, almost evenly distributed throughout the year, is normal (Yearbook of Agriculture, 1941).

A section is prepared to receive sludge by grading it to a very gentle slope and constructing 20 inch (50 cm) high terrace ridges to distribute sludge evenly. The lowest point in each section is equipped with a pipe underdrain which leads to a small oil trap for gravity separation of entrained oil before the water is discharged into the stream. Oil is retrieved for further treatment or is returned to the land.

After a section has been properly graded to assure even distribution, oily sludge and emulsions are brought from the refinery by vacuum truck and discharged into the enclosed section where it spreads to a depth of about six inches (15 cm). The sludge consists primarily of oily solids,but it may contain wax, entrapped water, and pockets of oil. The oil is recovered by vacuum truck for return to the refinery. After drainage of excess water and removal of free oil, a bulldozer is used to mix the sludge with about six inches (15 cm) of soil and stir the mixture to improve aeration and accelerate drainage. The stirring is repeated from two to four times each month until the soil returns to a brown friable condition indicating that biological oxidation has progressed far enough for oil to be added again. Stirring is an important part of the process as it keeps the mixture aerobic and disperses hydrocarbon molecules making them more readily available for microbial attack. The original mixture of equal volumes of oil and sludge is very oily and unpromising. Four sections are used so that as one is being filled another is prepared to receive sludge, and two others are decomposing the oils.

The time required to decompose the sludge varies from three to nine months with some of the most important determining factors being moisture content and temperature of the soil and the types of hydrocarbons applied. Wet soil has been observed to inhibit consumption of the sludge. Although a record of soil temperatures is not available, the temperature of a nearby pond averaged 75°F (23°C) with winter average being 42°F (5.5°C) and the summer being 99°F (37°C). Beerstecher (1954) gave 86°F (30°C) as optimum temperature for incubation of most hydrocarbon-oxidizing organisms.

Two types of hydrocarbons observed to be particularly resistant to microbial decomposition are paraffin waxes which form hard cakes that are difficult to mix with the soil and high molecular weight polyaromatic material. However, even these resistant materials are eventually decomposed.

At the beginning of the land disposal operation, the refinery conducted a pilot study to determine the rate at which hydrocarbons would decompose. Two open boxes containing 51 (23.3 Kg) and 56 pounds (25.4 Kg) of soil respectively were treated with oily sludge at the land disposal area. The soil and oil were mixed at irregular intervals and the oil content determined. The rate of decomposition varied from 5 to 60 pounds (80 to 960 mg/cc) per cubic foot of soil per month. A rapid rate of decomposition occurred with as much as 23% of oil by weight added to the soil. Though at a slower rate, oxidation did continue through the colder months of the year.

MICROBIOLOGICAL STUDIES

Although numerous investigators have reported the use of petroleum hydrocarbons for food by various microbes, not much information was available to indicate which genera would be most likely to increase in numbers and activity in the presence of oily waste in a warm humid climate such as in southeastern Texas.

In November, 1968, soil samples were taken for bioassay from three of the sections of the Shell Oil Company disposal area and from the relatively undisturbed soil outside.

Discharging oily waste into a section of a land disposal area at the Shell Oil Company's Houston Refinery

Samples one and two were from a relatively undisturbed soil outside of the disposal area. Three and four were from a section where oil was about mid-way through the decomposition phase of the cycle. Five and six represent an advanced stage of decomposition, and seven and eight were from a section that had recently received oil.

Samples were collected by a sterile sampling technique. One hundred twenty milliliter capacity sterile metal cans were pressed into the soil to obtain the sample. Plastic gloves and wood spatulas were used to protect the sample from contamination in handling.

BACTERIA

In the study of soils and oil-treated soils, agar pour plates were made of soil dilutions ranging from 10^{-1} to 10^{-8} in pH 7.2 buffer water. The numbers of bacteria per gram of soil were determined after three days' incubation at room temperature, for petri plates containing 30 to 300 colonies. The plating medium contained peptone, glycerol, magnesium chloride, potassium sulfate agar, and distilled water (King A medium). Colonies were chosen at random from the lowest count plates with the number of

Mixing oily sludge and soil at the Shell Oil Company's Refinery to accelerate dewatering, oxidation, and decomposition

colonies that could be characterized by the laboratory. Only aerobic species of bacteria were studied because many investigators have reported that anaerobes are inefficient decomposers of hydrocarbons.

Table 1 lists the types of bacteria found in the soil samples. *Pseudomonas stutzeri* was the species that showed the most rapid growth after application of the oily waste. The numbers of bacteria increased as the oil was decomposed until the food source decreased. Genera such as *Bacillus*, *Streptomyces*, *Achromobacter*, and *Flavobacter*, present in the untreated soil, did not increase as much in the oil-treated soil as the *Pseudomonas* species did, and were not even detected in samples three and four where the greatest number of bacteria was found. There were fewer bacteria per gram of oil-saturated soil indicating a probable toxic effect of volatile constituents in the oil.

FUNGI

Very little information is available in the literature concerning the ability of fungi to degrade wastes of the petroleum industry. As a result of observing molds growing in a

A section of the Shell Oil Company's disposal area where the biological decomposition rate is at its maximum

stream into which oil wastes from a refinery in west central Ohio were discharged, as well as interest in the availability to fungi of hydrocarbons as a source of nutrients, Cooke (1957) substituted S.A.E. 20 motor oil for glucose in a nutrition experiment in shaken flask culture. It was found that the ratio of growth in the motor oil to that in a solution containing glucose was 7.58 in the case of *Penicillium lilacinum*, 6.18 in *Geotrichum candidum*, 3.96 in *Rhinocladiella mansonii* and 2.49 in *Fusarium aquaeductuum*, all common fungi of polluted waters and sewages; while in other common species of molds these ratios were only between 0.50 and 0.75 in the cases of *Fusarium oxysporum*, *Penicillium melinii*, *P. ochro-chloron*, *Aureobasidium pullulans*, and *Trichoderma viride sensu lato*.

Crosby, Rudolfs and Heukelekian (1954) were more interested in the control of slime growths which appeared in various areas in oil refineries. However, they observed that in addition to several types of bacteria and blue green algae, filamentous fungi were present. They noted that as a result of their ability to adsorb oils such slime-forming organisms might be of potential significance in removing polluting substances from waste discharges from such plants. More recently, it has been noted that jet engine fuel tanks contain contaminating organisms.

TABLE 1
Aerobic Bacteria Found in Oily Sludge Treated Soil at the Shell Oil Company Refinery

Species and Genera	Achromobacter sp.*	Bacillus sp.	Flavobacter sp.*	Pseudomonas stutzeri	Pseudomonas sp.*	Streptomyces sp.*	Unknown sp.*
Area 1, Untreated soil, bacterial count/gm soil 4.25×10^7							
Number of strains	5	6	1		3	10	
% of total	20	24	4		12	40	
Area 2, Sludge treated soil, oil midway in oxidation, bacterial count/gm soil 6.5×10^7							
Number of strains				21	4		
% of total				84	16		
Area 3, Sludge treated soil, oil in advanced stage of oxidation bacterial count/gm soil 3.5×10^7							
Number of strains	3		3	17	2		
% of total	12		12	68	8		
Area 4, Sludge treated soil, very oily, bacterial count/gm soil 1.5×10^8							
Number of strains			8	4	10	1	2
% of total			32	16	40	4	8

*Species recognized but not identified were combined.

Reese, Cravetz and Mandels (1955) tested the activity of 358 cultures of fungi on coconut oil and a castor oil derivative, methyl-acetyl-ricinoleate. The medium used included 0.5 gm of oil in 50 ml nutrient solution using 1.0 g NH_4NO_3, 1.36 g KH_2PO_4, 0.2 g $MgSO_4 \cdot 7H_2O$, 0.1 g Difco yeast extract, in a liter of distilled water with the pH adjusted to 6.4. Ten of the species reported in the following study were included among the strains tested. Best results were obtained with *Aspergillus terreus* of this group. Others producing significant amounts of growth in this experiment were: *A. flavus, A. fumigatus, A. niger, Penicillium lilacinum, P. funiculosum, Trichoderma viride sensu lato, Myrothecium verrucaria, Aspergillus flavipes* and *Humicola fuscoatra*.

Coursey and Eggins (1961) studied microorganisms responsible for the spoilage of palm oil during storage. Of the 15 species of filamentous fungi they found, strains of at least one of those to be reported here were tested for lipolytic activity. *Aspergillus niger* was strongly lipolytic, while *Curcularia lunata* and *Aureobasidium pullulans (Torula nigra)* were present among the species isolated.

Nyus et al. (1968) tested a wide range of fungi to determine their ability to assimilate a series of hydrocarbon fractions. The orders *mucorales* and *moniliales* were found to provide the largest number of hydrocarbon-using classes. *Aspergillus* and *Penicillium* are genera which provide many strains that assimilate hydrocarbons.

METHODS USED IN FUNGAL EXAMINATION

The samples from Shell Oil Company refinery were plated, using pour plates, in dilutions of 1:100, 1:1000, and 1:10,000, in neopeptone-dextrose agar, and neopetone-dextrose-rose bengal agar, in all cases using tetracycline as a bacterial inhibitor. Dilutions of the samples were prepared in distilled water using a rotary shaker at about 150 oscillations per minute for breaking up and dispersing the soil particles in the sample. In the case of samples 3, 4, 5 and 6, approximately 75% of the 15 ml sample remained balled up in water resistant oil during this process so that probably only about ¼ of the amount of soil taken was actually sampled.

Table 2 lists the corrected, estimated numbers of colonies of fungi recovered from the samples. In calculating oven dry weights it was assumed that, like many samples of soils, these samples were approximately 67% dry material, 33% water. In the case of soils permeated by oil, this value may be too high. In the case of four samples, where incomplete dispersion resulted from shaking, the numbers of colonies obtained may have been low.

TABLE 2
Colonies of fungi recovered from oil soaked soils

Sample	Medium	Dilution	Avg. No. colonies per pair plates	Avg. No. colonies per ml Sample	Approx. Avg. No. colonies per gm "oven dry weight"	Average
Area 1						
1	RB*	1:10,000	40	400,000	1,300,000	
2	RB	1:10,000	11	110,000	380,000	840,000
Area 2						
3	RB	1:10,000	7	70,000	380,000	
4	RB	1:10,000	17	170,000	570,000	1,900,000*
Area 3						
5	ND	1:10,000	21.5	215,000	720,000	
6	ND	1:10,000	6	60,000	200,000	1,840,000*
Area 4						
7	ND	1:1,000	2.5	2,500	840	
8	ND	1:1,000	6	6,000	2,000	1,400

Table 3 lists the species of fungi recovered from the four areas sampled. In Table 3, data from pairs of samples have been composited.

Results of a preliminary study such as this indicate that fungi, both filamentous and yeast-like, are present in large numbers in soils subjected to receipt of oil wastes, especially where these soils and wastes are thoroughly mixed (aerated) periodically. While in a lagoon area to which oil wastes have been freshly applied the fungus count is low, as in samples 7 and 8, as the mixing and aerating process proceeds the count rises rapidly, reaching more than twice as many colonies in the treatment area as in the presumably

Table 3 lists the species of fungi recovered from the four areas sampled. In Table 3, data from pairs of samples have been composited.

TABLE 3

Species of fungi recovered from oil waste disposal samples

Species	Area			
	1	2	3	4
Unidentified molds	x	x	x	x
Aspergillus terreus	x	x	x	x
Penicillium lilacinum	x	x	x	x
Penicillium spp.	x	x	x	
Curvularia lunata	x		x	
Aspergillus niger	x		x	
Trichoderma viride	x		x	
Fusarium spp.	x		x	
Monosporium apiospermum	x			x
Mucor spp.	x			
Penicillium janthinellum	x			
Aspergillus flavus	x			
Cylindrocarpon destruens	x			
Myrothecium verrucaria	x			
Fusarium oxysporum	x			
Humicola grisea	x			
Aspergillus fumigatus		x	x	x
Rhodotorula aurantiaca		x	x	x
Diheterospora chlamydospora		x	x	x
White yeast spp.		x	x	x
Candida tropicalis		x		
Rhodotorula sp.		x		
Monascus sp.			x	x
Aspergillus flavipes			x	
Aspergillus sp.			x	
Torulopsis dattila			x	
Candida guilliermondii			x	
Aspergillus candidus			x	
Penicillium funiculosum			x	
Curvularia geniculata			x	
Humicola fuscoatra				x
Penicillium variabile				x
Leptographium sp.				x
Stilbella sp.				x
Total species – 34				
Total species from each sample	12–11	7–6	11–13	10–9
Total species from each area	16	10	19	14

undisturbed area nearby, if a correction is made for incomplete homogenization of the sample in water.

On the basis of this preliminary study it appears that there are species of fungi, strains of which can readily adapt to conditions of the soil waste disposal area from which the

samples were obtained. At least five species of filamentous fungi and one red yeast are common to all areas in which waste oil sludges are treated in this area near Houston, Texas. There is no reason to believe that similar populations are not present elsewhere.

The Marathon Oil Company at Robinson, Illinois, used land spreading to dispose of oily sludge from two lagoons in 1969. In contrast to the other disposal operations, sludge was spread only once. The lagoons which had been used as settling basins or clarifiers following a trickling filter in their old waste treatment system, were cleaned in preparation for construction of a new treatment plant. The sludge, accumulated over a period of five years, had an estimated average composition of 40% water, 25% ash, and 35% oil.

The land used for disposal purposes is owned by the refinery and is located adjacent to it. The soils are derived from loess mantled glacial till. They have a silt loam surface and a dense impermeable clay subsoil. They are nearly level, poorly drained, and strongly acid.

The climate at Robinson, Illinois, is cooler than at Houston, Texas, with an average January temperature of 32°F (0°C). The average for July is 76°F (24°C). The highest recorded temperature is 108°F (42°C), and the lowest is −18°F (−28°C). The average growing season of 182 days results from the first killing frost on October 18 and the last on April 19. Forty-two inches (105 cm) of precipitation are distributed almost evenly throughout the year (Yearbook of Agriculture, 1941).

The disposal procedure consisted of removing the sludge in May from lagoons with a clamshell, loading it into a dump truck, hauling to the field, and spreading. After a few days of drying the sludge was mixed with the soil to a depth of about 18 inches (45 cm) by disking. Two applications of sludge of about two inches (5 cm) were applied before disking.

A rainstorm occurring soon after some of the sludge was applied, and before cultivation, resulted in erosion of the oily sludge and deposition of it in a catch basin or small lake on refinery property. It was of sufficient magnitude to kill some fish in the lake. This incident illustrates the potential for water pollution from land spreading.

Soil samples were collected from the disposal area for assay of the bacteriological population in November, 1969. Samples one and two were taken from the last part of the field to receive sludge. Samples three and four were from a part of the field that received sludge first and was representative of the poorest drainage. Samples five and six were from an area of similar soils to the site of samples three and four, but no sludge had been applied. The microbial population may, however, have been influenced by the proximity of the refinery. Table 4 shows that the types of bacterial population in the untreated soil are different from those that have been in contact with the oily waste for about five months. The presence of hydrocarbons caused the inevitable growth of those types of bacteria and fungi which are most efficient at using the hydrocarbons for a food source and at growing under the environmental conditions produced by the addition of oily wastes. The principal hydrocarbon users are gram-negative, rod-shaped bacteria. The bioassay of the samples indicates that *Pseudomonas* species, particularly *Pseudomonas stutzeri*, made the greatest growth after the addition of oil and as a result Pseudomonads comprised over half of the population of the samples. Pseudomonads were not detected in the samples from the non-oil treated soil.

Oily sludge disposal area at Robinson, Illinois, partly disked

DISCUSSION

Many investigators have shown that microorganisms occurring ubiquitously in soils will attack petroleum hydrocarbons when they are added to soil. Unfortunately, the process is too slow for effective disposal of oily sludge or reclamation of soil after oil spills or leaks without some cultural practices to accelerate decomposition. Conditions favoring growth of most higher plants are generally favorable for aerobic microbes, so management of a disposal area can be patterned after a successful crop production enterprise. Anaerobic decomposition is very slow, and adding a large amount of oil to soil creates anaerobic conditions if no precautions are taken to aerate the soil. Oil not only occupies the pore space, thus excluding air from the soil, but it also greatly increases the oxygen demand for its own oxidation. Disking was the method first used to stir and aerate the soil by the three refineries, but the Shell refinery found that the disk compacted soil and interfered with aeration. The bulldozer was substituted and was found to leave the soil more loose and open, thus resulting in faster dewatering and better aeration. The oil-soil mixture is rolled by the blade much as oil dressing is rolled with soil for use on some secondary roads. Some of the hydrocarbons, particularly waxes and heavier oils, are more resistant to

TABLE 4
Aerobic Bacteria Found in Oily Sludge Disposal Area and in Adjacent Soil at the Marathon Oil Company Refinery at Robinson, Illinois

Species and Genera	Bacillus sp.	Streptomyces sp.	Alcaligenes sp.	Pseudomonas stutzeri	Sarcina sp.	Achromobacter sp.	Flavobacter sp.	Pseudomonas sp (black pigment)	Pseudomonas sp. B	Pseudomonas sp. Cy	Unknown
Soil without sludge, samples #5 and 6, bacterial count/gm of soil 1.05×10^5											
Number of strains	11	4	9								1
% of total	44	16	36								4
Soil treated with sludge, samples 1 and 2, bacterial count/gm soil 1.79×10^8											
Number of strains	2		1	12	2	4	2	2			
% of total	8		4	48	8	16	8	8			
Soil treated with sludge, samples 3 and 4, bacterial count/gm soil 1.03×10^8											
Number of strains	3	1	4	3					5	5	3
% of total	12	4	16	12					20	20	12

decomposition, partially because less surface is exposed to microbial attack. Dispersion of these by intimate mixing with soil particles apparently allows the organisms to attack and decompose these fractions faster. Mineral nutrients, particularly nitrogen and phosphorus, are important for microbial growth and activity. Although in none of the disposal operations studied was fertilization a regular practice, it appears likely that addition of an appropriate fertilizer would accelerate oxidation. Moisture is important to the microbes, but excess moisture, by impeding aeration, may be a limiting factor for microbial activity. Tile or surface drains may be needed for some soils.

Several changes in soil are reported to take place after introduction of hydrocarbons (Ellis and Adams, 1961). Investigators have reported a marked increase in organic matter, total carbon, and nitrogen. Davis (1952) reported natural deposits called "paraffin dirt" were composed of the residue of microbial cells which had utilized methane gas at the site of seepage. An analysis of the deposit showed that it contained 17.6% organic carbon and 1.2% total nitrogen. The amounts found in most natural soils are much lower. Plice (1948), while studying the effects of crude petroleum on soil fertility, found soil with organic matter content of 12.47% and nitrogen content of 0.81% near a gas leak, but at a distance of two feet (60 cm) the soil contained only 0.52% organic matter and 0.03% nitrogen.

Oil has the effect of deflocculating surface soils when it is applied to them. However, the eventual effect is to improve the soil tilth by increasing the organic matter content.

Large oil applications are often toxic to plants. The volatile fractions, which have great penetrating power, enter plants and seeds and have a narcotic effect on all living organisms. Reduction of manganese to the manganous form by the lowered oxidation-reduction potential caused by addition of oil creates toxicity also, but Plice (1948) reported that most of the damage to plants was caused by mechanical obstruction which prevented the plant from obtaining sufficient moisture and air.

Soil productivity may be enhanced by light applications of oil. Plice (1948) observed that petroleum additions of 0.5 to 1% by weight produced more luxuriant plants than those growing on check plots where no oil was added. He also noted that soils saturated with oil to a depth of more than four feet eventually returned to a productive state. One such soil remained barren and boggy for a few years, but after seven years was observed to be more productive than adjacent unaffected soil. Ellis and Adams (1961) cited the work of Carr (1919) in which he found that soybean growth was improved by adding a small amount of oil. Damage to some plants has been estimated to begin at more than 1 Kg/square meter of soil (Schwendinger, 1968). A number of organic acids from petroleum industry wastes have been shown to stimulate plant growth. Weak solutions of napthenic acid increased significantly root length of cotton, cucumbers, onions, and winter wheat (Husinov, 1960).

Deep, fine-textured soils were used for the disposal sites. Oil is known to adhere to such soils and move but little into them, thus eliminating danger of ground water pollution, if oil is added judiciously. Only indiscriminate, heavy additions of oil to coarse, porous, or shallow soils would be expected to cause such pollution.

The use of land spreading to dispose of oil spills collected on beaches has been proposed (R. Stone, Santa Monica, California, personal communication, 1969). Air movement through the sandy soil behind beaches might be enhanced by tidal changes in the ground water levels and this would favor rapid decomposition of oil and any straw used to help collection of the oil. As in all other land disposal practices, it will be imperative to avoid overdosing and the creation of tightly packed impervious lumps of oil and soil. When straw is used, additional supplies of nitrogen may be necessary because of the high nitrogen requirement for decomposition of the straw.

CONCLUSIONS

1. Soil microbes can oxidize and decompose a large quantity of petroleum hydrocarbons under a wide range of soil and environmental conditions.
2. Land spreading is an economical and comparatively foolproof method of disposing of oily wastes.
3. Although large additions of oil may create toxic conditions for plants, the eventual effect upon soil is to improve physical and chemical properties by increasing organic matter and nitrogen content, decreasing volume weight and increasing porosity and moisture holding capacity.
4. Natural biochemical decomposition of oil in soil may be accelerated by judicious use of lime and fertilizer, artificial drainage, and tillage.
5. Microbiological degradation of oily wastes takes place under a wide range of temperature, but oxidation is faster in warm or hot climates than it is in cold.

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